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DECISION RISK ANALYSIS FOR XM204, 105MM Howitzer, Towed Reliability/Durability Requirements

BY

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APRIL 1973

SYSTEMS ANALYSIS DIVISION

PLANS AND ANALYSIS DIRECTORATE

US ARMY WEAPONS COMMAND

ROCK ISLAND, ILLINOIS

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13. ABSTRACT

There is a continuous discussion between the user and the designer as to what the optimal reliability and durability requirements for a weapon system such as a howitzer should be. This analysis develops a rationale for the reliability and durability requirements for the XM204, 105mm Towed, Howitzer while simultaneously defining a plan to test for these requirements. The system reliability requirements, subsystem durability requirements, reliability and durability uncertainties of the proposed design, and the number of prototypes and test length to establish reliability and durability parameters, are related to expected cost.

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There is a continuous discussion between the user and the designer as to what the optimal reliability and durability requirements for a weapon system such as a howitzer should be. This analysis develops a rationale for the reliability and durability requirements for the XM204, 105MM Towed, Howitzer while simultaneously defining a plan to test for these requirements. The system reliability requirements, subsystem durability requirements, reliability and durability uncertainties of the proposed design, and the number of prototypes and test length to establish reliability and durability parameters, are related to expected cost.

TABLE OF CONTENTS

SUMMARY

This report represents a first effort in an attempt to present management/decision makers a composite picture of the relationship of reliability, durability, testing and risk by including quantification of the uncertainties that the "on-the-board" designers and engineering analysts feels with regard to each subsystem within his cognizance. In order to obtain answers to the question of interest, a collection of mathematical models were developed which represent the relationships among these variables. These relationships were grouped together in the form of computer programs to comprise a Monte-Carlo simulation. A search over the decision space (e.g., durability requirements, no. subsystems to test) was then conducted to develop an "optimized solution" in terms of expected life cycle cost.

The simulation and programs are available upon request but are not included within this report. Several technical reports have been initiated as a result of this effort and will be published in the near future. A complete documentation of the simulation is planned. The authors are available for comments on any and all aspects of the simulation and this report.

Based on the assumptions of this study, there is a small probability of passing DT/OT-II with the original baseline requirements (Table 3).

$$P[\text{passing DT/OT-II}] = .218 \quad .$$

The risk (expected loss) associated with these parameters:

Risk = \$6.238 billion

The search program, BIG SEARCH, examined the parameter space and recommended the parameters presented in the Table below. There were significant reductions in the requirements with the exception of tube durability. The tube durability requirements were raised by BIG SEARCH retaining the small probability of passing DT/OT-II. This led to the "state-of-the-art" recommendation. Reduction of the tube durability requirement will decrease the probability of rejection, but at the same time will significantly increase the expected loss due to the additional maintenance burden. However, one assumption associated with system rejection is that a system can be developed which meets the specified requirements determined by BIG SEARCH. This is thought to be realistic with respect to fatigue failures, ignoring weight constraints, but not realistic with respect to tube wear.

If it can be determined that the tube development for the XM204 represents the state-of-the-art design with respect to tube wear, then it is recommended that tube wear be ignored as a rejection criterion. If this is done then the expected loss is reduced to

Risk(E[loss]) = \$6.223 billion

and the probability of passing DT/OT-II is increased

P(passing DT/OT-II) = .61 .

The recommended test plan shows a requirement for a large number of back-up subsystems, with the exception of the carriages as well as a slight decrease in the truncation point.

The chart below depicts the original requirements and test plan vs. the recommendations of this study.

	Original		Recommended*	
	Accept	Reject	Accept	Reject
Durability				
Carriage	22,500	22,500	21,000	13,500
Recoil	22,500	22,500	10,500	6,000
Tube	7,500	7,500	State-of-the-art	
Breech	22,500	22,500	16,000	7,500
Reliability	1,500	1,500	1,500	400

Test Plan	Original	Recommended
No. of Carriages	3	3
No. of Recoils	1	5
No. of Tubes	3	13
No. of Breeches	1	3
Rounds/Weapon	22,500	20,000

* The interval between accept and reject is a "fix-up" region. In this region additional funds are expended to bring the subsystem (system) to the acceptable level, or a decision is made to accept the lower figure (See Loss Function).

INTRODUCTION

There is a continuous discussion between the user and the designer as to what the reliability and durability requirements for a weapon system should be. This is particularly true for weapon systems which are primarily mechanical such as howitzers. The user documents a need (through the MN or ROC process) for a system possessing reliability and durability significantly higher than previous systems. The designer on the other hand feels the user should accept any system which is at least as good as the existing weapons reliability and durability, since the new design will undoubtedly possess other characteristics such as increased range, reduced weight, etc. which the designer feels are the primary reasons for the new system and are, in themselves, inversely related to reliability/durability. (He has never been asked to design a totally new system strictly to increase reliability or durability.) When the discussions are over and a compromise is reached, the true benefit of the agreed-to requirement to the Army is questionable. Each side attempts to provide enough documentation to support its position.

This analysis develops a rationale for the reliability and durability requirements for the XM204, 105mm Towed, Howitzer while simultaneously defining a plan to test for those requirements. The system reliability requirement, subsystem durability requirements, reliability and durability uncertainties of the proposed design, and the number of prototypes and test length to establish reliability and durability parameters, are related to expected costs.

Certain of these factors are identified as variables. This lends to consideration and evaluation of alternative courses of action with the objective of reducing expected life cycle costs. The expecced loss (life cycle cost for this analysis) of an alternative is identified as the risk of that alternative in accordance with standard statistical terminology[1].

This report is structured to present, in sequence, the requirements to be quantified and the uncertainty of the design engineers, regarding expected reliability and durability, followed by the loss function which relates actions (e.g., accept or reject system) to test data and the true value of the parameters. The input data is discussed including the test and maintenance costs followed by a test plan which contains an example of how the test cost and test statistics are generated and what decision would be made based on them. The study recommendations are then presented along with a sensitivity analysis of the input variables and the resulting conclusions.

The report is repleat with strong assumptions which are identified and which lead to some suggestions for a follow-on analysis.

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[1] Ferguson, T.S., Mathematical Statistics, A Decision Theoretic Approach, Academic Press, 1967.

REQUIREMENTS

As a result of DT/OT-II decisions will be made as to the acceptability of the entire system from a reliability viewpoint and on each of the four major subsystems from a durability viewpoint. Therefore reliability requirements must be specified for the total system and durability requirements must be specified for each major subsystem. It was assumed that a truncated test would be preferred to a fire to failure test for planning purposes. Therefore, a maximum number of rounds to be fired on each system or the truncation point must be specified. As a total system configuration is required to conduct the test, the number of systems to be put on test must be specified along with the number of spare or replacement components. Also since statistical techniques produce not one but a family of alternative statements from the same test, the confidence level associated with the test must be specified. Additionally, each reliability and durability requirement must be specified. Rejection, fix and acceptance region were specified by the pairs (R_1, R_2) for reliability and (D_1, D_2) for durability (defined in the section "Loss Function"). Combining the above, the following set of requirements must be specified to define the requirements and statistical test environment for DT/OT-II.

System:

Number of systems on test

Reliability acceptance MTBF - R_1

Reliability rejection MTBF - R_2

Truncation Point - T_p

Confidence Level

Subsystem:

Number of spare subsystems - N

Durability acceptance MTBF - D_1

Durability rejection MTBF - D_2

The subsystem requirements must be specified for each major subsystem which are: the carriage, the recoil, the tube and the breech.

QUANTIFICATION OF PERFORMANCE UNCERTAINTIES

Research scientists and design engineers were interviewed to quantify their expectations regarding durability of the subsystems under their cognizance. Reliability expectations were developed by the WECOM Product Assurance Directorate based upon failure and stress data from the M102, 105mm Towed, Howitzer and expected stress levels and failure modes of the XM204.

The primary technique used to quantify the durability of the subsystem was presented by Stanford Research Institute at the 1972 US Army Operations Research Symposium. In essence, the design engineer is required to choose between two lotteries. Lottery No. 1 concerns the durability of the subsystem. The design engineer will win, say, one million dollars if the durability of the subsystem will be demonstrated less than X rounds (X is specified by the interviewer). Lottery No. 2 concerns the spin of a pointer on a wheel, see Figure 1. The design engineer will win one million dollars if the pointer falls within the red sector. After a choice has been made

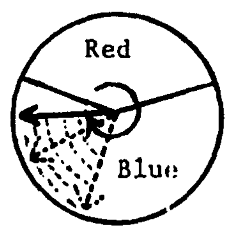


Figure 1

by the interviewee, the red sector is increased or decreased with the object of making the interviewee indifferent between the lotteries. When the indifference has been obtained, the percentage of the exposed red

sector is recorded as the belief of the interviewee in the occurrance of the event - subsystem durability is less than X rounds.

P[durability < X] = % red sector

The process is repeated for various values of X until a probability distribution can be drawn. Two experts were interviewed for most of the major subsystems for which a durability requirement exists. The experts were either engineers working on the design of the subject subsystem or physical scientists with knowledge of the subsystem.

Figures 2 through 7 present:

a. The raw data; responses between interviewees are distinguished by symbols.

b. The distribution fared through the raw data.

c. Optimistic and pessimistic distributions used for sensitivity analysis.

The distributions were "eyeballed through the raw data with weighting toward the data of the more expert of the interviewees. The optimistic and pessimistic curves were drawn to maintain the "shape" of the distribution through points approximately 25% on either side of the median (50th percentile) estimate.

These data were input to the computer simulation in the form of a discrete distribution. The probability content of an interval was obtained (by subtraction of probability values at endpoints of the interval) and assigned to the midpoint of the interval. These distributions are presented in Table 1 for the distribution fit to the data.

The distributions quantify the uncertainty associated with the expected number of rounds to failure. The breech safe life and tube fatigue safe life were estimated to be one-third of this value. The expert opinion on the minimum safe life was higher than the optimistic estimates on tube wear life; this led to consideration of only tube wear in regard to estimating tube durability

TABLE 1

PRIOR DISTRIBUTION ON MEAN-ROUNDS-TO-FAILURE PARAMETER

SUBSYSTEM

	CARRIAGE		RECOIL		TUBE		BREECH		RELIABILITY	
	MID-PT	PROB	MID-PT	PROB	MID-PT	PROB	MID-PT	PROB	MID-PT	PROB
1	2500	.05	2500	.24	4250	.32	48750	.03	1050	.10
2	7500	.05	7500	.14	4750	.16	56250	.07	1150	.15
3	12500	.05	12500	.13	5250	.12	63750	.40	1325	.15
4	17500	.04	17500	.15	5750	.10	71250	.30	1450	.10
5	22500	.04	22500	.15	6250	.10	78750	.13	1725	.15
6	27500	.04	27500	.16	6750	.08	86250	.07	2000	.10
7	32500	.08	32500	.03	7250	.06			2350	.10
8	37500	.15			7750	.06			2625	.05
9	47500	.25							3000	.05
10	52500	.25							3500	.05

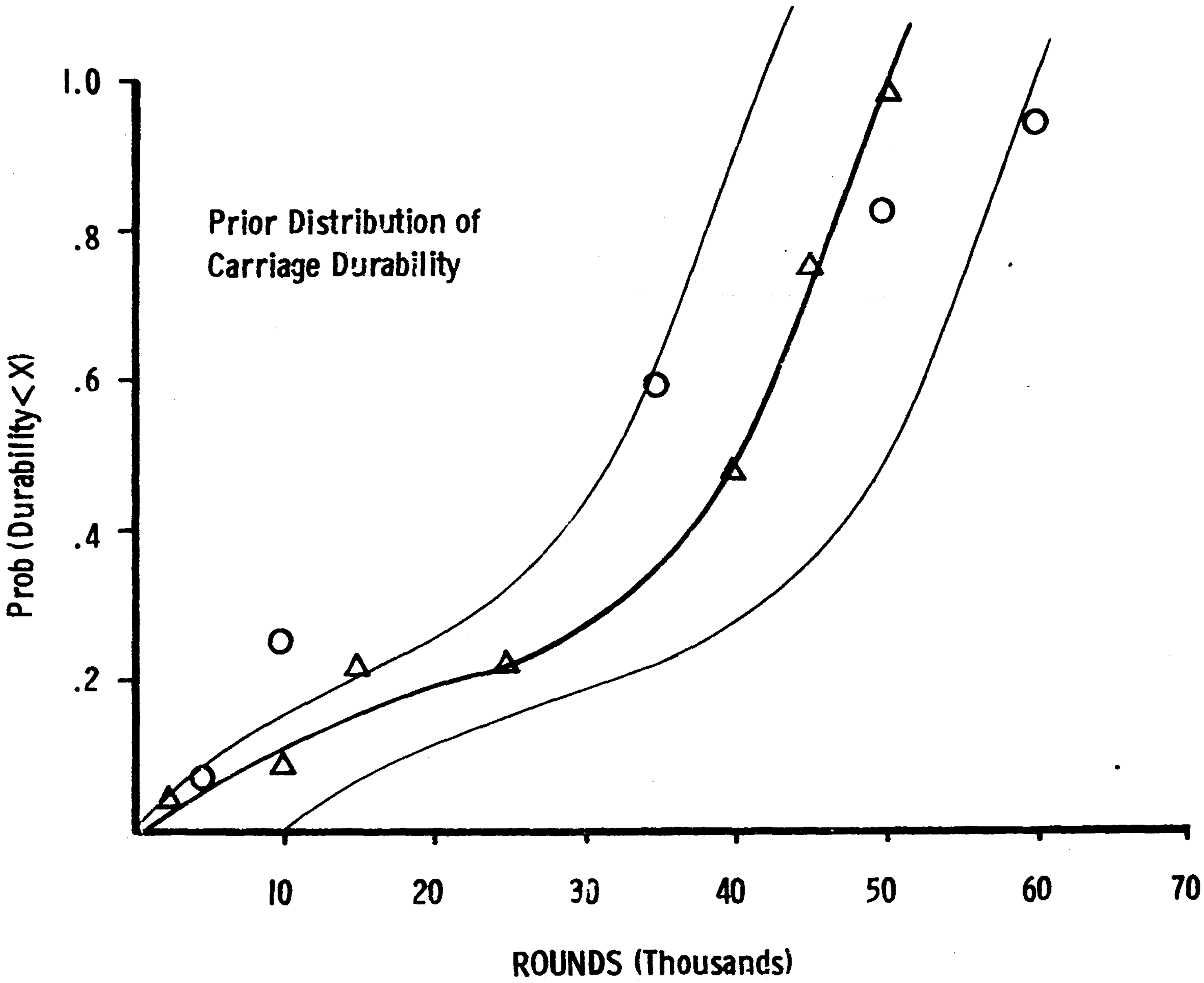

Prior Distribution of
Carriage Durability
Prob (Durability< X)
1.0
.8
.6
.4
.2
10
20
30
40
50
60
70
ROUNDS (Thousands)

Figure 2

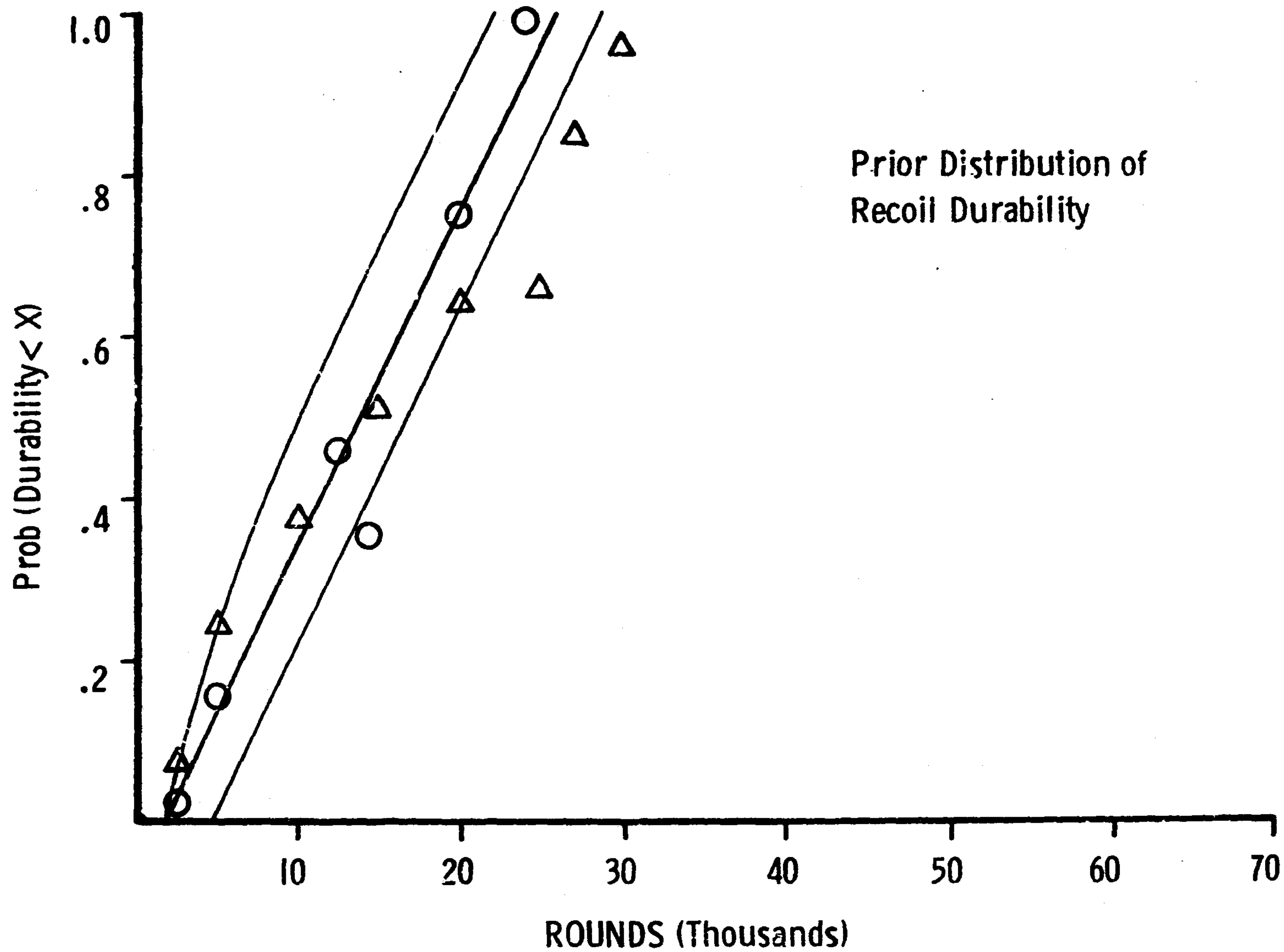
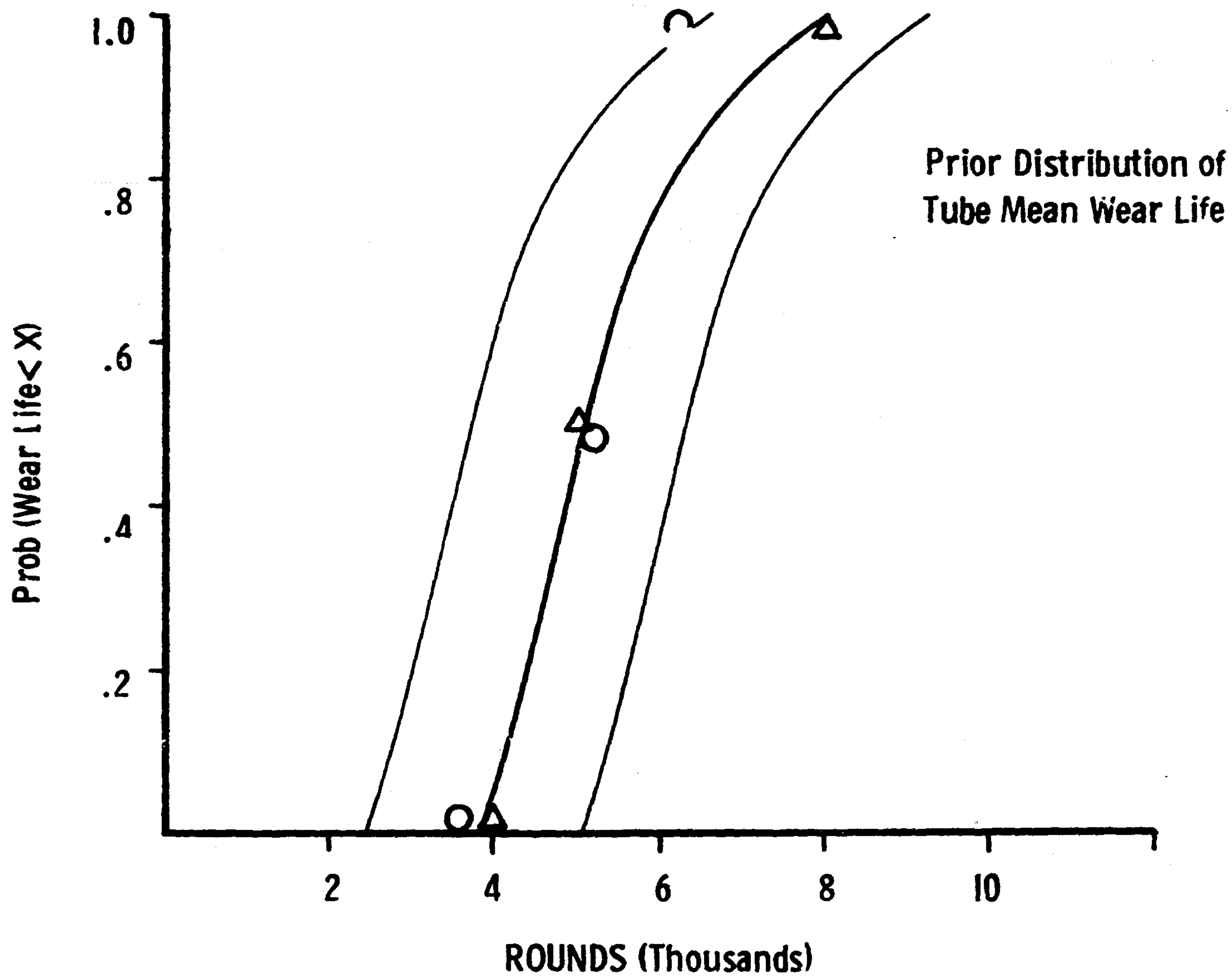

Prior Distribution of
Recoil Durability
Prob (Durability< X)
1.0
.8
.6
.4
.2
10
20
30
40
50
60
70
ROUNDS (Thousands)

Figure 3



Prior Distribution of
Tube Mean Wear Life
Prob (Wear Life< X)
1.0
.8
.6
.4
.2
2
4
6
8
10
ROUNDS (Thousands)

Figure 4

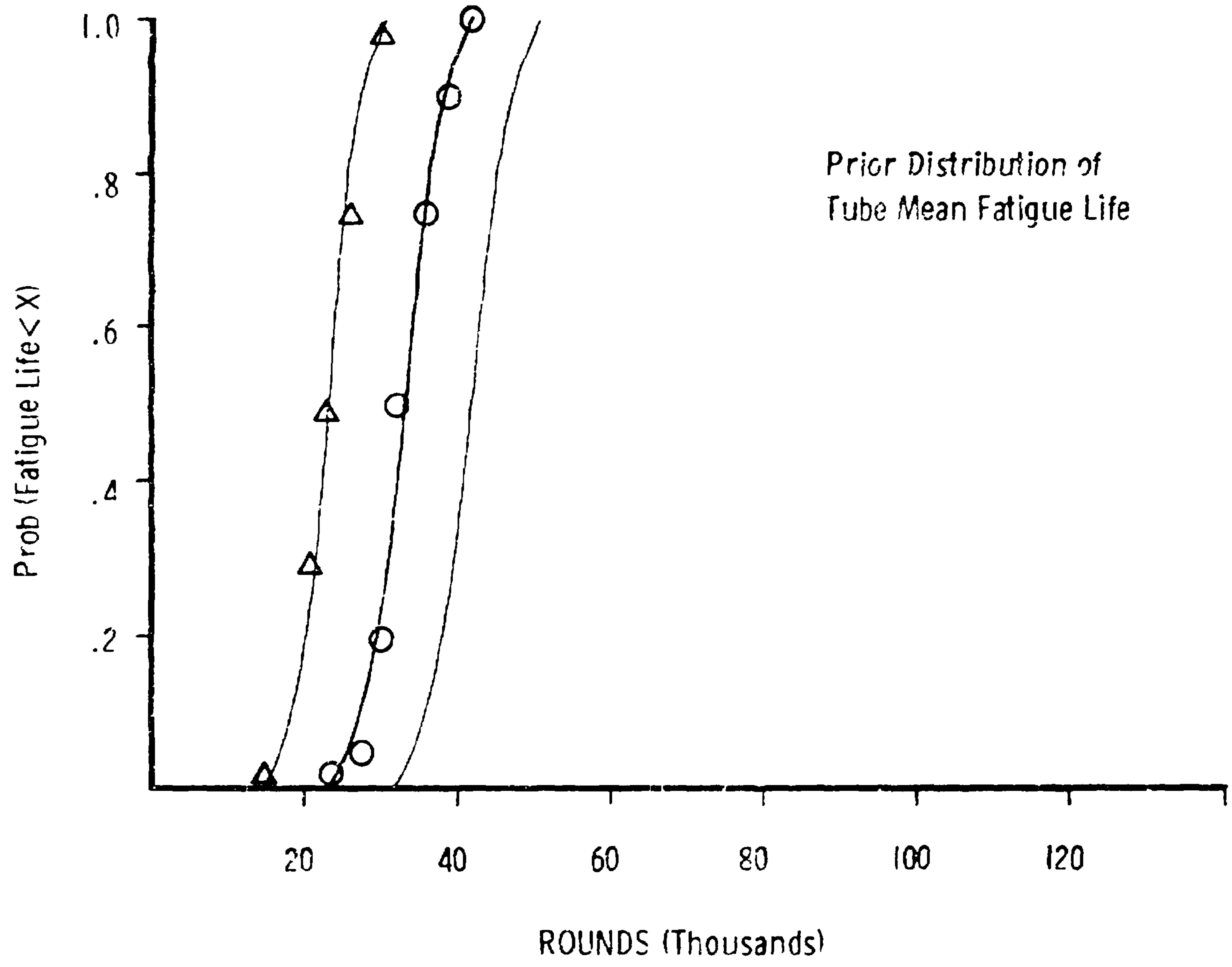

Prior Distribution of
Tube Mean Fatigue Life
Prob (Fatigue Life < X)
1.0
.8
.6
.4
.2
20
40
60
80
100
120
ROUNDS (Thousands)

Figure 5

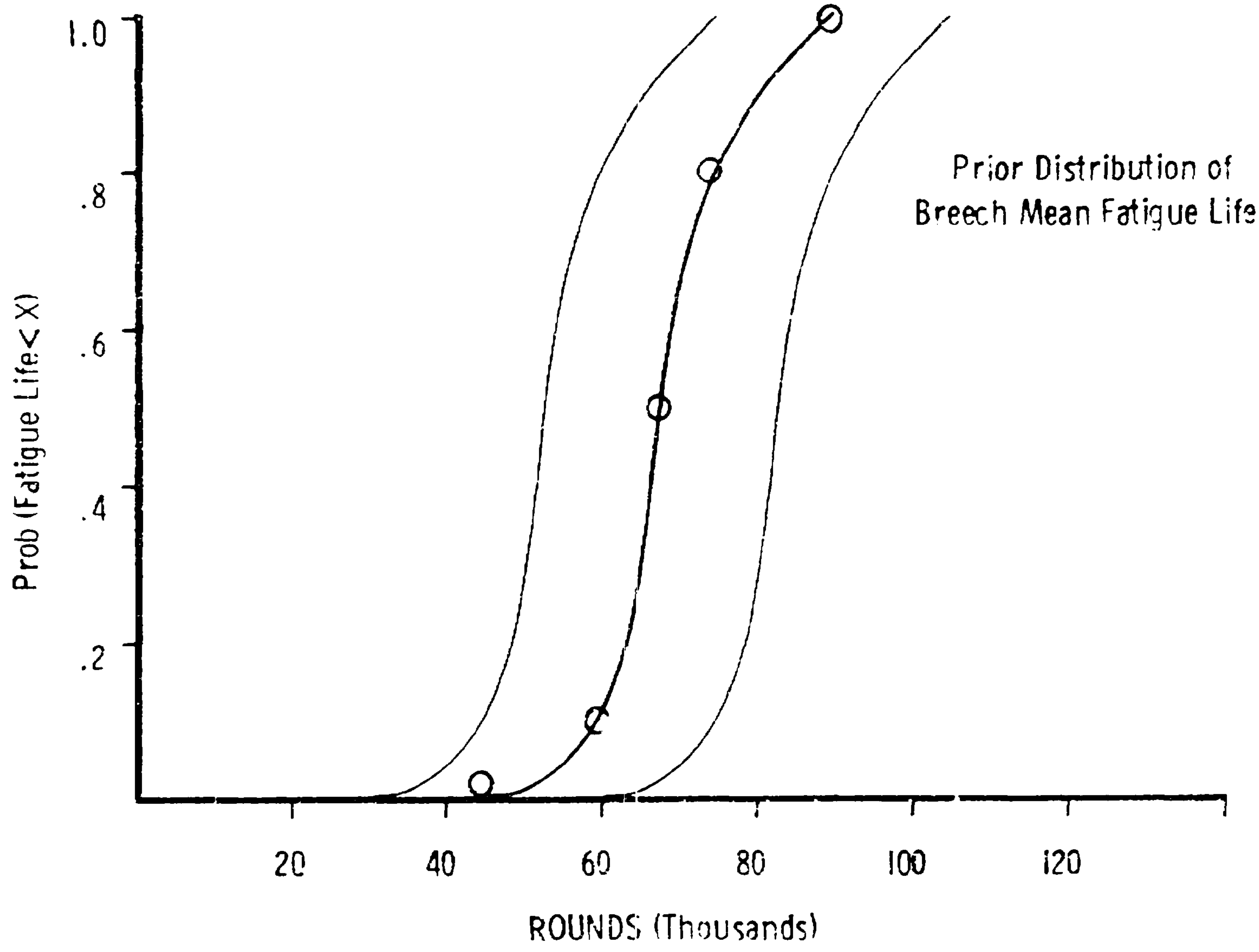

Prior Distribution of
Breech Mean Fatigue Life
Prob (Fatigue Life< X)
1.0
.8
.6
.4
.2
20
40
60
80
100
120
ROUNDS (Thousands)

Figure 6

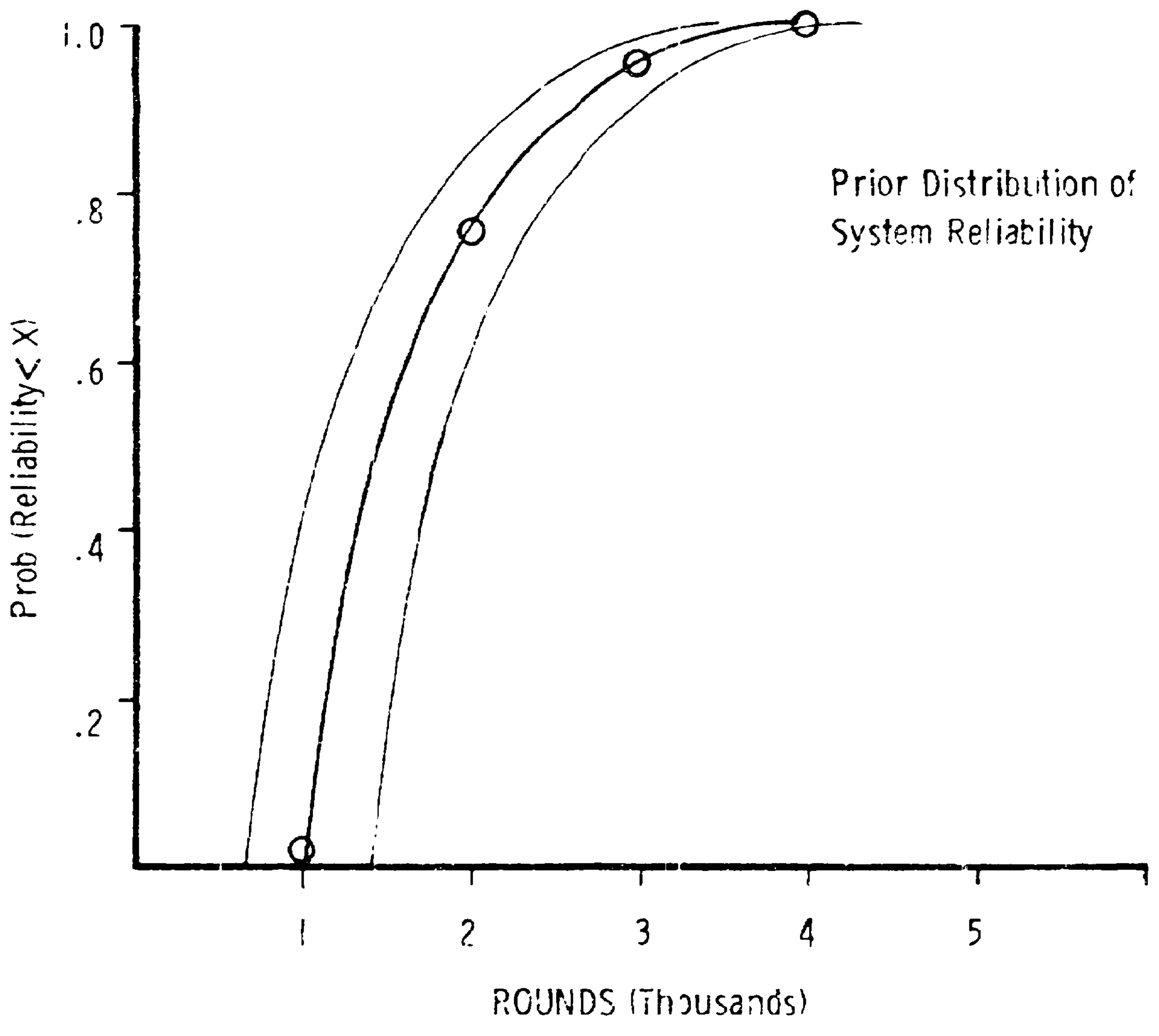

1.0
.8
.6
.4
.2
Prob (Reliability< X)
1
2
3
4
5
ROUNDS (Thousands)
Prior Distribution of
System Reliability

Figure 7

THE LOSS FUNCTION

The purpose of the loss function is to estimate the expected losses (expenditures) which will occur when action is taken in accordance with the belief that the state of the system is S' when, in fact, it is S.

The contractually specified performance parameters, reliability ($\underline{R}$) and durability (D), are considered to be bounded by military necessity or cost-effectiveness. From the military necessity standpoint, reliability can be translated into the requirement that a battery, fire on the average, a specified number of rounds during a mission. A system with a lower reliability will, on the average, fire fewer rounds. Increasing the number of systems per battery will achieve this goal of a minimum-expected-number-of-rounds/battery/mission. If the resulting design of the systems does not meet the specified limits, this alternative can be used as an upper bound on the cost of the second alternative, that being to "fix-up" a marginal system. In all cases an additional alternative is to cancel the program and live with the existing system. The term "fix-up" as used here means that a reliability growth program will be entered. A sequence of design-test cycles will be conducted until the reliability is grown to the required level.

Similarly, durability is a requirement on the life of a system. Durability can be translated into the requirement that a system, on the average, survives a specified number of rounds before requiring an

overhaul, or replacement when overhaul isn't applicable (i.e., tubes). A system with a lower durability will, on the average, survive fewer rounds before an overhaul is required. The cost of this lower than desired system durability can be estimated by the expected increase in overhaul/maintenance actions, over a suitable time frame.

Reliability Loss Function, $L(R,R')$

Definitions:

R - true value of system reliability

$\hat{R}$ - statistical estimate of R based on test data

R' - $=R_2$ if $\hat{R}$ not significantly less than R_2 (based on statistical test of hypothesis)

$=\hat{R}$ if $\hat{R}$ is significantly less than R_2

R_1 - a value of R' which is less than or equal to R_1 is cause for system rejection

R_2 - a value of R' which is greater than or equal to R_2 is cause for system acceptance with regard to reliability. This value is viewed as a requirement designed to insure that the expected number of rounds fired by a battery in a particular mission will not be below a specified level.

$L(R,R')$ - is the costs incurred in taking a course of action when R is the true reliability and R' its estimate.

Consider a pair (R_1, R_2) to be defined such that if the true system reliability R were known, the following actions would occur (depending on R):

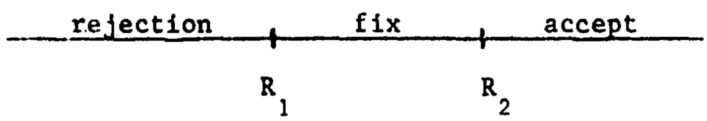
1. $R \leq R_1 \Rightarrow$ Action: Reject entire system

2. $R_1 < R < R_2 \Rightarrow$ Action: Fix - the system will be made acceptable, by entering a reliability growth program or fielding more systems per battery to insure the expected number of rounds criterion.

3. $R_2 < R \Rightarrow$ Action: Accept the system with respect to reliability.

Unfortunately, the value of R is not known. Statistical techniques will provide an estimate, $\hat{R}$, from test data. This value will be compared to R_2 to determine if $\hat{R}$ is significantly less than R_2 on a statistical basis. If the test does <u>not</u> show a significant difference then action will be taken as though $R' \geq R_2$, otherwise we will take action as though $R' = \hat{R}$.

Consider the reliability decision space divided into three regions as shown below.



The actual or true reliability, R, could fall into anyone of the three regions. In addition, when we test the system the estimate R' could also fall into anyone of the three regions. As we increase the sample size of our test R' should asymptotically approach R, however, the cost of the test will also increase. As we lower the test cost or reduce the

sample size then the expected difference between R and R' will increase. Therefore, there are nine possible states that could occur. They are:

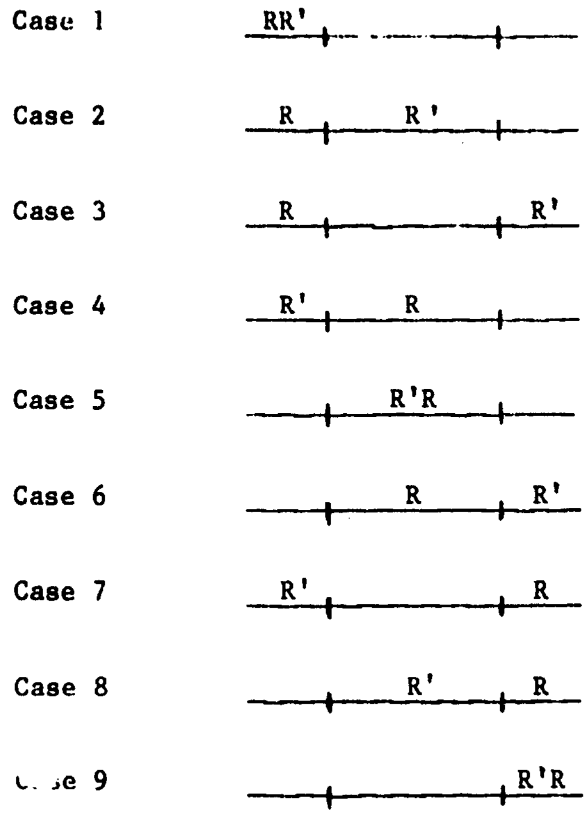


Figure 8

The following discussion outlines a method for estimating the expected losses incurred for each of the three possible decisions when, in fact, R is the true system reliability. The nine cases as outlined in Figure 8 are grouped according to the decision that is made. Contained within the discussion of each case are several cost figures which are referred to as C_1,C_2,C_3, etc. The rationale in developing these cost figures are contained in the section "Cost Derivation." The definition of each are as follows:

C_1 - The cost of extending the life of the present (M102/M101A1) system during a new development program (6 years)

C_2 - The cost of a new development program

C_3 - Cost of procuring and operating a second generation design during the remaining planned life (14 years)

C_4 - Cost of the planned first years procurement

C_6 - Cost of a redesign effort to correct a $\underline{R}$ failure mode

C_7 - Cost to procure one XM204

C_9 - Cost to operate and maintain one XM204 over 20 years

<u>Decision</u>:

Accept: RR' - Case 9

Under this case the true system R is acceptable and as a result of the test the system is accepted. The correct decision is made and the only cost incurred are the cost to procure and the cost to operate the weapon over the 20-year life cycle. The cost of reliability failures over the 20-years is based on the actual MRBF of the system.

$$L_9(R,R') = (C_7+C_9)(\text{No of Systems}) + (947.65)(\text{Total Rnds})/(\text{MRBF})$$

Accept: R R' - Case 6

Under this case the true system R lies within the fixup region and as a result of the test the system is accepted. An incorrect decision was made and the cost associated with this decision are as follows. Since it is thought that the system is good we go ahead with the first years production. However, after the first years production it is assumed that

it will now be discovered that the true R is not as good as thought. A product improvement program is initiated and the system reliability is grown via a redesign-test cycle until the true system R is acceptable. Now since one years production has already been made a retrofit program will be needed. To cost this out it was assumed that it would cost a factor of two times the cost of an ordinary reliability growth program had it been determined (i.e., the right decision made) before the first years production was made, that the true R was not acceptable.

$$L_6(R,R') = (C_7+C_9)(\text{No of Systems}) + (2)(\underline{R}\text{ growth cost})$$

Accept: R ——————— R' - Case 3

Under this case the true system R is definitely not acceptable, but as a result of the test the system is accepted. An incorrect decision was made and the cost associated with it are as follows. Since it is thought that the system is good we go ahead with the first years production. It is assumed that it will now be discovered that the true system R is definitely unacceptable, and the total system will be rejected. The cost of the first years production will be lost and a new development program will be initiated. The present system will have to be maintained and operated during the new development program which is assumed to last six years, per AR 1000-1.

$$L_3(R,R') = C_1 + C_2 + (C_3)(\text{No of Systems}) + C_4$$

Note: It is assumed that as a result of the new development program the new system will meet the specified MN requirements - This applies to all cases where a new development program is entered.

Reject RR' - Case 1

Under this case the true system R is unacceptable and as a result of the test the system is rejected. The correct decision was made. A new development program will be entered and the life of the present system will be extended. In addition, the cost of the prototypes and test cost for the first design will be lost.

$$L_1(R,R') = C_1 + C_2 + (C_3)(\text{No of Systems}) + \text{Cost of Prototypes} + \text{Test Cost}$$

Reject: R' R - Case 4

Under this case the true system R lies in the fixup region. As a result of the test the system is rejected. Therefore the cost described for Case 1 are incurred.

$$L_4(R,R') = C_1 + C_2 + (C_3)(\text{No of Systems}) + \text{Cost of Prototypes} + \text{Test Cost}$$

Reject: R' R - Case 7

Under this case the true system R is acceptable. As a result of the test the system is rejected. Therefore the cost described for Case 1 are incurred.

$$L_7(R,R') = C_1 + C_2 + (C_3)(\text{No of Systems}) + \text{Cost of Prototypes}$$
$$+ \text{ Test Cost}$$

Fixup: ——|—— R'R ——|—— - Case 3

Under this case the true system R lies in the fixup region. As a result of the test the reliability growth program is initiated. The correct decision was made. The cost and length of the growth program is based on the minimum of the true and estimated reliability. Rationale: If $R > R'$ we would allocate enough dollars to grow the program from R'. Once the funds are allocated it is seldom that they are returned. If $R' > R$ once the growth program is entered it will soon be obvious that R is not as high as thought and the system will not pass the test until the true R is acceptable.

$$L_5(R,R') = (C_7+C_9)(\text{No of Systems}) + \text{Cost of } \underline{R} \text{ Growth Program}$$

Fixup: ——|—— R' ——|—— R —— - Case 8

Under this case the true system R is acceptable. As a result of the test a reliability growth program is initiated. Funds will be allocated based on R'. It should soon be learned that the true R is acceptable, but since the funds have been allocated the growth program will continue. This will increase the true R which will lower the total life cycle reliability cost.

$$L_8 = (C_7 + C_9)(\text{No of Systems}) + \text{Cost of } \underline{R} \text{ Growth Program}$$

Fixup: R R' - Case 2

Under this case the true R is unacceptable. As a result of the test a reliability growth program is initiated. The funds for the growth program will have been sunk and soon it will be realized that the system should be rejected. Consequently, a new development program will be started, and the cost of Case 1 will also be incurred.

$$L_2(R,R') = C_1 + C_2 + (C_3)(\text{No of Systems}) + \text{Cost of } \underline{R} \text{ Growth Program}$$

Durability Loss Function L(D,D')

There are two basic differences between the reliability loss function and the durability loss function. The first is that there are durability requirements at the subsystem level while reliability requirements are only at the system level. The second is in the concept of fixing a marginal system for reliability vs. accepting an increased maintenance burden for durability.

Definitions:

- D - true value of subsystem durability
- $\hat{D}$ - estimate of subsystem D based on test
- D_1 - a value of D' which is less than or equal to D is cause for subsystem rejection
- D_2 - a value of D' which is greater than or equal to D is cause for subsystem acceptance with regard to durability

$$D' = D_2 \quad \text{if} \quad \hat{D} \ \text{not significantly less than} \ D_2$$
$$= \hat{D} \quad \text{if} \quad \hat{D} \ \text{is significantly less than} \ D_2$$

For each subsystem a pair (D_1, D_2) will be defined such that if the true subsystem durability D were known the following actions would occur, (depending on the value of D).

1. $D \leq D_1 \Rightarrow$ Action: Reject subsystem

2. $D_1 \leq D \leq D_2 \Rightarrow$ Action: Fixup - The cost incurred to maintain the subsystem at D vs. D_2 will be used as an upperbound for the cost of this action.

3. $D_2 \leq D \Rightarrow$ Action: Accept subsystem, plan to maintain subsystem based on D_2 being the true durability.

However, the value of D is not known. Statistical techniques will provide an estimate $\hat{D}$ from test data. This value will be compared to D_2 to determine if $\hat{D}$ is significantly less than D_2 on a statistical basis. If the test does not show a significant difference then action will be taken as though $D' \geq D_2$, otherwise we will take action as though $D' = \hat{D}$.

Similar to the reliability decision space, the durability decision space is divided into three regions as shown below:

Reject | Accept/Marginal | Accept

D_1 D_2

As with reliability the true durability D could fall into anyone of the three regions as could the estimate D'. Therefore, there are nine possible states that could occur. They are:

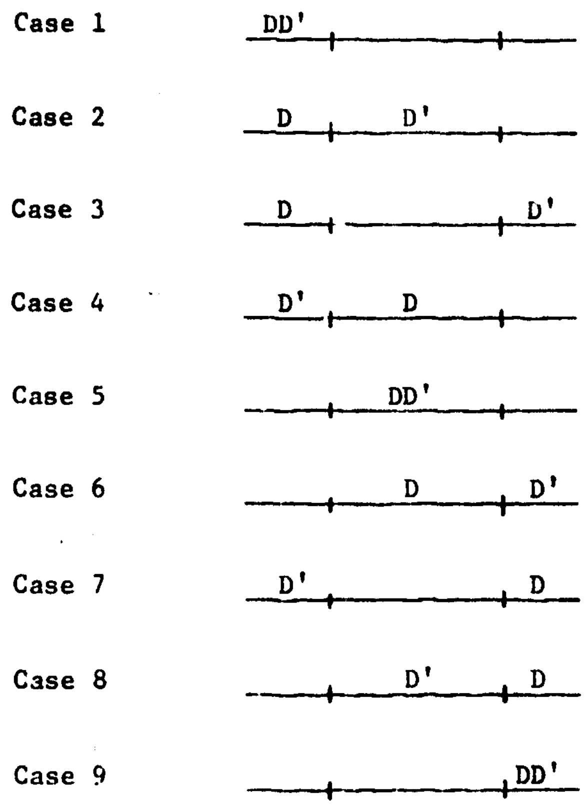


Figure 8

There are only three instances where the decision would be to reject the subsystem, namely Cases 1, 4 & 7. If any subsystem is rejected then the cost incurred are the same as those that would occur for a reliability rejection. A new development program will be entered and the life of the present system will be extended. In addition the cost of the prototypes and the test cost for the first design will be lost.

$$L_{1,4,7}(D,D') = C_1 + C_2 + (C_3)(\text{No of Systems}) + \text{Cost of Prototypes} + \text{Test Cost}$$

In all other cases the subsystem will be accepted, however, the expected number of renewals $E[N]$ (overhauls) will differ depending on the decision space. For Cases 2,3,6 & 9 the expected number of renewals will be calculated based on the true mean time between durability failure D. For Case 8 the estimate D' will be used to calculate the expected number of failures. And for Case 5 the minimum of D and D' will be used.

$$L_{2,3,5,6,8,9}(D,D') = (E[N])(\text{Cost/overhaul})(\text{No of systems})$$

For Cases 2,3,6 & 9 the test estimate D' is the mean time between overhaul the subsystem is thought to have. Once the end item is fielded, the true durability D is the actual maintenance burden that will be exhibited, therefore, the expected number of renewal based on D is the true cost. It would have been planned to overhaul at D' but, on the average, the subsystem would have to be overhauled at D.

For Case 8 the planned overhaul time would be based on D' and since $D > D'$ it will not be possible to take advantage of the full designed durability. Therefore, the $E[N]$ is based on D'.

For Case 5 the calculation of $E[N]$ is based on the $\text{Min}(D,D')$. If $D > D'$ then D' will be used as for Case 8. If $D' > D$ then D will be used as for Cases 2,3,6 & 9.

<u>Total Loss</u>

The total expected cost if the system is accepted, is the sum of the reliability and durability losses. However, if any subsystem is rejected

for durability or if the system is rejected for reliability then a total redesign stage is entered. It is assumed that no matter what magnitude of improvement is required during the redesign stage, when the "new" system is tested it will meet all MN requirements regardless of what level the requirements are set at. The expected number of durability and reliability failures for the "new" design are calculated on the basis of the MN requirements over the remaining 14 (20-6) years.

COST DERIVATION

Cost of the Reliability Growth Program

The observed reliability, R', of the system during DT/OT-II may satisfy the relationship

$$R_1(\text{rejection}) < R' < R_2(\text{acceptance}) \quad .$$

The system is considered marginal and further development will be required to increase the reliability.

Studies performed by AMSWE-QA have shown that the reliability growth of WECOM commodities can be approximated by the relationship

$$\log \theta = \alpha \log t + \beta \tag{1}$$

where

θ = mean rounds between failure

t = time on test .

The implicit assumption is the above relationship is that failure modes are observed in testing and ameliorated by redesign.

Under the assumption that reliability failures are exponentially distributed, the mean-rounds-between-failure (MRBF) of the system is computed as

$$\theta_0 = -(\text{mission duration})/\log_e(\text{mission reliability})$$

Consider the case in which θ_r is the required value of θ, but during DT/OT II it is recognized that

$$\theta_0 < \theta_r \quad .$$

Consider that the value θ_0 is not cause for system rejection so that a reliability improvement program is initiated.

The first phase of the program addresses redesign to ameliorate the conditions discovered during DT/OT II. This effort increases the MRBF to where:

$$\log(\theta_1) = \alpha \log(t) + \log(\theta_0) \tag{2}$$

$$\theta_1 = t^{\alpha} \theta_0$$

where

t = total rnds fired on test.

The last term in Equation 2 was derived from the assumption that the MRBF of the system after the first rounds of testing was θ_0.

Further testing-redesign cycles will increase the reliability according to Equation 1. Assume that every failure observed in test is the subject of a redesign effort which causes this increase in reliability. After the redesign of the components, the expected time to the next observed failure is θ_1. The increase in reliability as a result of this observation-redesign sequence is θ_2:

$$\log \theta_2 = \log \theta_1 + \alpha \log \theta_1$$

$$= \log \theta_1^{\alpha+1}$$

or

$$\theta_2 = \theta_1^{\alpha+1} \quad .$$

Similarly,

$$\theta_3 = \theta_2^{\alpha+1}$$

$$= \theta_1^{(\alpha+1)^2}$$

and

$$\theta_n = \theta_1^{(\alpha+1)^{n-1}}$$

To meet or exceed the required θ_r

$$\theta_n \geq \theta_r$$

$$\log \theta_1^{(\alpha+1)^{n-1}} \geq \log \theta_r$$

$$(n-1)\log(\alpha+1) \geq \log(\log \theta_r/\log \theta_1)$$

$$n \geq 1 + \frac{\log(\log \theta_r/\log \theta_1)}{\log(\alpha+1)} = n' - \varepsilon$$

where

n' is an integer

and $0 \leq \varepsilon < 1$.

Therefore the expected number of redesign efforts is n'. The expected number of rounds fired is

$$t' = \sum_{i=1}^{n'-1} \theta_i$$

or

$$t' = \sum_{i=1}^{n'-1} \theta_1^{(\alpha+1)^{i-1}}$$

The total expected cost of the reliability program is:

$$\text{Cost of Rel. Growth} = t' \cdot c_r + n' \cdot c_e$$

where

c_r = cost to fire one test round

c_e = expected cost to redesign and fabricate components

C_1 - The cost of extending the life of the present system (M102/M101A1) during a new development program (6 years). Six years is assumed as the maximum time for a redevelopment program based on AR 1000-1 guidelines.

Rounds per year - In determining the average expected rounds to be fired per year per weapon, a 20 year useful life was considered. CDC recommended that for each 10 year period consider 8 years peace and two years war. The MN mission profile was used for wartime usage and CTA 23-100-6 was used for peacetime usage.

(4 yrs war) (145 mission/yr) (100 efc/missions)	=	58000
(16 yrs peace) (250/yr)	=	4000
Average efc rounds/yr = 3100		62000 efc/20 yrs

Annual operating cost

Repair Parts	(3100) (.84/rd*)	2604.0
Ammo	(3100) ($7640/253*)	93610.7
I. L. S.		6243.0*
Overhaul Cost	($10,755/overhaul)(3100) / (20,000 rd/overhaul)	1667.0
		167881.7
Crew		67723.0*
Overhaul		1605.0
		167209.7

*Ref. cost figures furnished from SWERR-A-SM (Appendix A)

Six year operating cost/weapon

C_1 = (\$1,003,258) · (No of systems deployed)

C_2 - Cost of a new development program, "a new development program" here means that the present (1^{st}) design of the XM204 does not pass DT/OT and a total redesign effort is initiated. Cost wise, this will be assumed that it will last for six years (AR 1000-1). This includes the time from initial redesign through another DT/OT test phase.

The present total planned cost for the XM204 development	=	\$20,000,000.0
This consists of R&D development cost + prototype cost + DT/OT cost. The R&D development cost is	=	14,754,000.0
Expected prototype + DT/OT cost	=	5,246,000

However, the prototype cost and the test cost will be a function of the test design, that is, the number of test weapons and total number rounds fired.

$$C_2 = \$14,754,000 + \sum_{i=1}^{4} C_i N_i + E[\text{No of rds fired}] \quad (\text{cost/rd})$$

where C_i = cost of i^{th} subsystem

N_i = number of subsystem plus spares for the test

C_3 - Cost of procuring and operating one weapon of the second generation design during the remaining planned life (14 years). It is implicitly assumed that this "second" design will meet the specified MN requirements.

C_3 - Cont'd

Cost to procure	$ 57,000.0
<u>Annual operating cost/system</u>	
Crew	67,723.0
Overhead	1,178.0
Ammunition (3100) ($7,640/253*)	93,610.7
I. L. S.	6,243.0
	$168,754.7

<u>Repair parts costs</u>

Average cost of a part replacement for a <u>R</u> failure**	=	378.05
Add 50% stock, store and issue cost plus an average of 3.5 man-hours @ $7.50/hr to get the average cost of a <u>R</u> failure		593.32
This $593.32 is in 1969 dollars. The inflation rate to FY 73 cost (Table I of CP letter)		X 1.21
		717.92
Since we are costing out for 20 years starting in 1975, (i.e., 1975-1995) the 1985 inflation rate will be used as an average (Table V of CP letter)	=	1.32
		947.65

Repair parts cost = $947.65 x E (No of <u>R</u> failures)

$$= \frac{(947.65)\ (\text{Total rnds fired})}{(\text{MRBF})}$$

<u>Overhaul cost</u>

= E[No of overhauls for recoils] x cost/recoil

+ E[No of tube replacements] x cost/tubes

+ E[No of carriage overhauls] x cost/carriage

+ E[No of tube replacements/3] x cost/breech

C_3 - Cont'd

The breech replacements are based on replacing the breech after every three tubes

$$C_3 = \text{(Procurement Cost)} + 14 \cdot \text{(Annual Operating Cost)}$$
$$+ \text{(Reliability Repair Parts Cost)} + \text{(Durability/Overhaul Cost)}$$

Procurement Cost	=	57,000.0
14 x Annual Operating Cost	=	2,362,565.8

$$C_3 = 2419565.8 + \frac{947.65 \text{ (Total Life)}}{\text{(MRBF)}} + \text{Overhaul Cost)}$$

* ref. CP cost figures furnished by SWERR-A-SM (Appendix A)

** based on M102 data -- (does not include Recoil, Tube, Breech or Cannon)

NOTE: Expected number of overhauls/replacements used in the overhaul cost are calculated based on Steady State renewal rates (i.e., 1/MRBF). Recognizing that this is a pessimistic value, it is felt that this does represent a reasonable upper limit on the number of overhaul/replacements.

C_4 - Cost of planned one year procurement.

The estimated cost of the first year's procurement based on SWERR-A-SM estimates is = $7,347,500.00

This includes building 28 weapons and the associated Engineers Support Cost, tooling and gage cost programmed for FY 76

C_6 - Cost of a redesign effort to correct a $\underline{R}$ failure mode. When a reliability growth program is entered a part or subsystem will be redesigned and the "new" redesigned component will then be built for further testing. Design engineers provided the following estimates for the cost of the redesign effort which includes the cost to build the new parts.

From SWERR-A-SM

"a" - optimistic value = \$500.

"m" - most likely value = \$3,000.

"b" - pessimistic value = \$10,000.

Assuming a Beta distribution the expected cost is

$$E[T] = \frac{a+4m+b}{6} = \frac{(500)+(4)(3000)+10000}{6} = \$3,750 \quad .$$

$$\tau_T = 1/6(b-a) = 1/6(10000-500) = 1583.33$$

$$f(x) = \frac{x^{p-1}(1-x)^{q-1}}{\beta(p,q)} \qquad \text{where} \qquad \beta(p,q) = \frac{\Gamma(p)\Gamma(q)}{\Gamma(p+q)}$$

$$\text{mean} = \bar{x} = \frac{E[T]-a}{b-a} = \frac{3750-500}{9500} = .3421$$

$$(q-1) = 1/\bar{x} + 2 = (1/.3421) + 2 = 4.92312$$

$$q = 5.92312$$

$$M_x = \frac{M_t-a}{b-a} = \frac{3000-500}{9500} = .26315$$

$$(p-1) = (q-1)\ M_x/(1-M_x) = \frac{(4.92312)(.26315)}{(1-.26315)} = 1.75817$$

$$p = 2.75817$$

The value of C_6 is then obtained by randomly sampling from the distribution defined by

$$f(x) = \frac{x^{1.75817}(1-x)^{4.92312}}{\beta(2.75817,5.92312)}$$

C_7 - Cost to procure one XM204.

The present estimate of the production cost on one XM204 is = \$57,000.00

C_9 - Cost to operate one XM204 over its projected life (20 years); does not include overhaul and parts replacement cost.

Crew	\$ 67,723.0*
Overhead	1,178.0*
Ammunition (3100) (7640/253)	93,610.0*
Integrated Logistic Support	6,243. *
	\$168,754.7/year
	20 years
	\$3,375,094.0

*Cost from SWERR-A-SM

PARAMETER SPACE

The procedure adopted for pursuing the objective of the study was to search over the relevant variables as presented in Table 2, and choose that combination which yields the lowest expected loss.

The system reliability requirement for the XM204, states a minimum acceptable average number of rounds between failure (MRBF), Ref. 1. This requirement assumes MRBF to be constant during the operating life of the system. A constant MRBF will be assumed for this study with respect to reliability. Subsystem durability requirements are expressed in terms of a subsystem operating no less than a specific number of rounds with a specified probability; e.g.,

$$\text{Prob [Subsystem Life} > 500 \text{ rounds]} \geq .5$$

A direct search with acceleration was adopted for searching the parameter space for parameter vectors yielding lower expected losses. This routine makes steps on either side of the baseline to establish a direction for each of the parameters (variables in this context) and takes larger or smaller steps in the established direction (constrained by a specified number of step cuts), until not further improvement can be made in the objective function, which in this case is expected loss.

The initial baseline reliability/durability validation test plan and requirements are presented in Table 3. The test of hypothesis

confidence level (Table 3, A6) pertains to the test conducted on the statistic under consideration. (i.e. test data is used to generate a statistic which estimates durability, say $\hat{D}$. Is D significantly different than the desired durability D_2?) The probability associated with the reliability/durability parameters (Table 3 B1-4) are shown in Figure 10.

	Subsystem		Durability		Probability
1)	Prob (Carriage Failure	<	22,500)	<	.50
2)	Prob (Recoil Failure	<	22,500)	<	.50
3)	Prob (Tube Wear Failure	<	7,500)	<	.50
4)	Prob (Tube Fatigue Failure	<	7,500)	<	.001
5)	Prob (Breech Fatigue Failure	<	22,500)	<	.001

Figure 10

TABLE 2

A. Test Parameters

1. No. Carriage Subsystems

2. No. Recoil Subsystems

3. No. Tubes

4. No. Breech Subsystems

5. Truncation Point (Each carriage will fire to failure or truncation point)

6. Test-of-Hypothesis Confidence Level

B. Reliability/Durability Parameters

1. Reliability Rejection Region $(0,R_1)$

2. Reliability Acceptance Region (R_2,∞)

3. Durability Rejection Region $(0,D_1)$

   a. D_1 (Carriage)

   b. D_1 (Recoil)

   c. D_1 (Tube)

   d. D_1 (Breech)

4. Durability Acceptance Region (D_2,∞)

   a. D_2 (Carriage)

   b. D_2 (Recoil)

   c. D_2 (Tube)

   d. D_2 (Breech)

TABLE 3

BASE LINE PARAMETERS

A. Test Parameters

1. No. Carriage Subsystems - 3
2. No. Recoil Subsystems - 3
3. No. Tubes - 12
4. No. Breech Subsystems - 3
5. Truncation Point - 22,500
6. Test-of-Hypothesis Confidence (Assumed) - 90%

B. Reliability/Durability Parameters

1. Reliability Rejection, $R_1 = 1500$
2. Reliability Acceptance, $R_2 = R_1$
3. Durability Rejection, $(0, D_1)$
   a. D_1 (Carriage) = 22,500
   b. D_1 (Recoil) = 22,500
   c. D_1 (Tube) = 7,500
   d. D_1 (Breech) = 22,500
4. Durability Acceptance, (D_2, ∞)
   a. D_2 (Carriage) = D_1 (Carriage)
   b. D_2 (Recoil) = D_1 (Recoil)
   c. D_2 (Tube) = D_1 (Tube)
   d. D_2 (Breech) = D_1 (Breech)

TEST PLAN

During DT/OT a certain number (N_1) of howitzers will be placed on test. For testing purposes the howitzer is composed of one critical subsystem (the carriage) and several major non-critical subsystems (recoils, tubes & breeches). Each howitzer will be fired until one of two events occur:

(1) a carriage durability failure occurs,

(2) a specified number of rounds, t_p, have been fired.

A maintenance support test package will accompany each weapon and among its contents will be N_k spare prototypes for each of the major non-critical subsystems (N_2 - Recoil, N_3 - Tube, N_4 - Breech).

A total system configuration is required to conduct the test, however with respect to probability of failure, each subsystem is assumed independent. During the course of the test as each non-critical subsystem durability failure occurs, the failure time is noted, and the failed subsystem is replaced until either:

(a) all of the spare prototypes of type k have suffered a durability failure,

(b) the carriage has suffered a durability failure or has fired t_p rounds.

If all of the spares of a particular type subsystem have failed before (1) or (2) above occur, then that subsystem will be "patched-up" to allow the

test to continue until either (1) or (2) does occur. However, no additional information will be collected on that weapon for that subsystem.

When a reliability failure occurs for any subsystem the failure time is noted and the failure is repaired to allow the test to continue. The repair will be assumed as-good-as-new and each reliability failure is assumed independent.

A hypothetical design and observation of this type of test is shown in the following example:

Example 1:

Number of Carriages, N_1	3
Number of Recoils/carriage, N_2	4 (original + 3 spares)
Number of Tubes/carriage, N_3	7 (original + 6 spares)
Number of Breeches/carriage, N_4	2 (original + 1 spare)

t_p = 22,500 rounds

The above test design depicts a test where three howitzers will be fired for a maximum of 22,500 rounds each. Each carriage has three spare recoils, six spare tubes, and one spare breech in its maintenance support test package.

Example: (Cont'd)

Test Observations

	Reliability Failures	Durability Failures
Carriage #1	3083, 5667, 15594	15597
Recoil #1.1	8766, 10729	No observed failure
Tube #1.1		6648
Tube #1.2		8823
Tube #1.3		14402
Tube #1.4		No observed failure
Breech #1.1		No observed failure
Carriage #2	8020, 16672	No observed failure
Recoil #2.1		9166
Recoil #2.2	13587, 18178	20293
Recoil #2.3		No observed failure
Tube #2.1		6822
Tube #2.2		13339
Tube #2.3		20122
Tube #2.4		No observed failure
Breech #2.1	22498	No observed failure
Carriage #3	5552, 9229, 18178	No observed failure
Recoil #3.1	11443	11666
Recoil #3.2		16674
Recoil #3.3	22498	No observed failure
Tube #3.1		7270
Tube #3.2		17924
Tube #3.3		No observed failure
Breech #3.1		No observed failure

Example: (Cont'd)

The above failure times are the number of rounds on the carriage at the time the failure occurred. Carriage #1 had a durability failure at 15597 rounds at which time all testing was stopped on that weapon. Testing on Carriage #2 and #3 was stopped at the predetermined truncation point of 22,500 rounds.

Associated with weapon #1 were five reliability failures which occurred at the times shown. Three of the reliability failures occurred on the carriage and two occurred on the recoil. The original recoil did not have a durability failure and lasted until the carriage failed or 15597 rounds. The original tube was replaced at 6648 rounds, the first spare was replaced at 8823 rounds, and the second spare was replaced at 14402 rounds. The last tube did not fail in the remaining 1195 rounds. The original breech survived the 15597 rounds.

Associated with weapon #2 were five reliability failures, two which occurred on the carriage, two which occurred on the 1st spare recoil and one which occurred on the breech. The original recoil was replaced at 9166 rounds and the 1st spare was replaced at 20293 rounds. The second spare survived the remaining 2207 rounds. Three tubes were replaced at 6822, 13339 and 20122 rounds respectively. The last tube survived the remaining 2378 rounds. The original breech survived the total 22,500 rounds.

Associated with weapon #3 were five reliability failures, three which occurred on the carriage, one on the original recoil and one on the

2^{nd} spare recoil. The original recoil was replaced at 11666 rounds and the 1^{st} spare was replaced at 16674 rounds. The second spare survived the remaining 5826 rounds. Two tubes were replaced at 7270 and 17924 rounds respectively. The last tube survived the remaining 4576 rounds. The original breech survived the total 22,500 rounds.

Test Cost

The total test cost is the sum of the prototype cost and the firing cost. For this example these are as follows:

1. Prototype Cost = $(N_1)\cdot$(Cost/carriage) + $(N_1)\cdot(N_2)$(Cost/recoil)

   + $(N_1)\cdot(N_3)\cdot$(Cost/tube) + $(N_1)\cdot(N_4)\cdot$(Cost/breech)

   = (3)(Cost/carriage) + (12)(Cost/recoil)

   + (21)(Cost/tube) + (6)(Cost/breech)

2. Firing Cost = (Rnds fired on Carriage #1 + Rnds fired on Carriage #2

   + Rnds fired on Carriage #3)$\cdot$(Cost/round)

   = (15597 + 22500 + 22500)(Cost/round)

Test Statistics

The observations as outlined in Example 1 were generated from the two parameter Weibull distributions as shown below. Along with the true values are shown the estimates which are based on the observations.

	True	Estimate
Carriage		
	Shape parameter = 2.48642	$\hat{\alpha} = 3.15846$
	Scale parameter = $.449008 \times 10^{-11}$	$\hat{\lambda} = .775047 \times 10^{-14}$
	with MTBF = 31,613 rounds	$\hat{\mu}$ = 26,152 rounds
Recoil		
	Shape parameter = 1.21277	$\hat{\alpha} = 2.05138$
	Scale parameter = $.487712 \times 10^{-5}$	$\hat{\lambda} = .379892 \times 10^{-8}$
	with MTBF = 17,728 rounds	$\hat{\mu}$ = 10,644 rounds
Tube		
	Shape parameter = 1.995004	$\hat{\alpha} = 2.833641$
	Scale parameter = $.2712387 \times 10^{-7}$	$\hat{\lambda} = .1150474 \times 10^{-10}$
	with MTBF = 5,164 rounds	$\hat{\mu}$ = 6,371 rounds
Breech		
	Shape parameter = 1.911326	-
	Scale parameter = $.7511622 \times 10^{-9}$	-
	with MTBF = 5,352 rounds	-
Reliability		
	Shape parameter = 1	$\alpha = 1$
	Scale parameter = $.26666 \times 10^{-3}$	$\hat{\lambda} = .28058 \times 10^{-3}$
	with MTBF = 3,750 rounds	$\hat{\mu}$ = 3,564 rounds

Consider the following as the requirements for the test

	Carriage	Recoil	Tube	Breech	Reliability
D_1	11,000	8,000	5,000	15,000	
D_2	22,500	22,500	7,500	22,500	
R_1					1,790
R_2					3,795

then based on the test results the following decision would be made.

Durability

Carriage - Accept - Case 9

Recoil - Accept - Case 5

Tube - Accept - Case 5

Breech - Accept - Case 3

Reliability - Fixup - Case 6

RECOMMENDATIONS

In accordance with the definitions prescribed within this report, the following table outlines the "optimized" results of the simulation.

TABLE 4

Test Description

N_1 - Number of Prototypes to be put on Test - 3

N_2 - Number of Spare Recoils/Prototypes - 5

N_3 - Number of Spare Tubes/Prototypes - 13

N_4 - Number of Spare Breeches/Prototypes - 3

Max Number of Rounds to be Fired/Prototypes - 20,000

Confidence Level for Test of Hypotheses - 90%

Requirements

Carriage	D_1	-	13,500
	D_2	-	21,000
Recoil	D_1	-	6,000
	D_2	-	10,500
Tube	D_1	-	*
	D_2	-	*
Breech	D_1	-	7,500
	D_2	-	16,000
Reliability	R_1	-	400
	R_2	-	1,500

*No Recommendation, See Section "Sensitivity and Conclusions"

With the above test description and requirements, the expected total test cost is $6,423,010.80 which can be broken down into $3,751,500 for prototype cost and $2,671,510.80 for ammunition. Other expected values associated with the simulated test are shown below in Table 2.

TABLE 5

Sample Size = 500

E[N] Carriage Failures During the Test = .948

E[N] Recoil Failures/Carriage = 5.68

E[N] Tube Replacements/Carriage = 8.494

E[N] Breech Failures/Carriage = .144

	Number of Occurrences for Each Case *								
Case No.	1	2	3	4	5	6	7	8	9
Carriage Durability	50	2	15	1	0	27	0	2	403
Recoil Durability	149	0	10	11	1	55	2	4	268
Tube Durability	-	-	-	-	-	-	-	-	-
Breech Durability	0	0	0	6	1	127	1	0	365
System Reliability	0	0	0	0	0	136	0	2	250

*See Section "Loss Function" for definition and explanation of each case.

Probability of Not Rejecting System at DT/OT-II

Carriage Durability	=	87.6%
Recoil Durability	=	71.4%
Tube Durability	=	-
Breech Durability	=	99.0%
System Reliability	=	100.0%
TOTAL SYSTEM	=	61%

Expected Total 20 year life cycle cost = $6,223,908,800.00

SENSITIVITY AND CONCLUSIONS

A sensitivity analysis was conducted by varying the input probability distribution for each subsystem and system reliability as outlined in the section "Quantification of Performance Uncertainties." The difference in the total 20 year life cycle cost as compared to the "optimized case" are shown below.

Subsystem	Direction	Difference ($\$ \times 10^6$)
Carriage	Pessimistic	+ .991
	Optimistic	- 2.789
Recoil	Pessimistic	+ 2.6414
	Optimistic	- 2.7834
Tube	Pessimistic	+ 31.9099
	Optimistic	- 6.5098
Breech	Pessimistic	+ 5.1265
	Optimistic	- 2.3168
Reliability	Pessimistic	+ .6306
	Optimistic	- 7.2014

The esimtate of the standard deviation σ for the total life cycle cost, due to random occurrance is $\approx \$1.3846 \times 10^6$, therefore $2\sigma = 2.7692$ and $3\sigma = 4.1538 \times 10^6$.

Since the tube showed the highest variability and was considerably outside the 3σ range it was decided to further study the tube durability

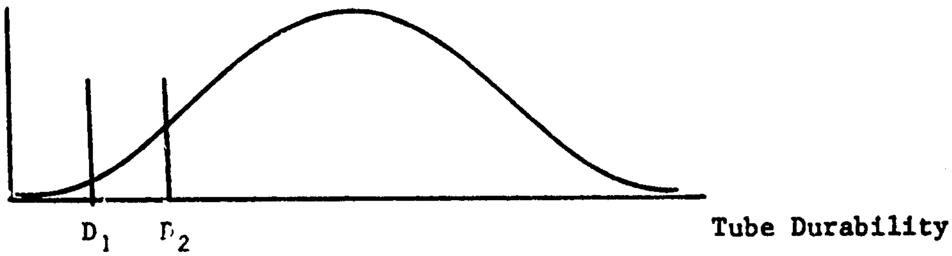
requirements. Holding all other parameters at the "optimized" values, the parameters D_1 and D_2' for the tube were varied with the following results.

	Life Cycle Cost	Probability of Acceptance/ Without Redesign
$D_1 = D_2 = 1{,}000$	6.647478×10^9	100%
$D_1 = D_2 = 3{,}000$	6.313495×10^9	99.9%
$D_1 = D_2 = 5{,}000$	6.254015×10^9	95.6%
$D_1 = D_2 = 7{,}500$	6.243281×10^9	59.2%
$D_1 = D_2 = 10{,}000$	6.238615×10^9	27.6%

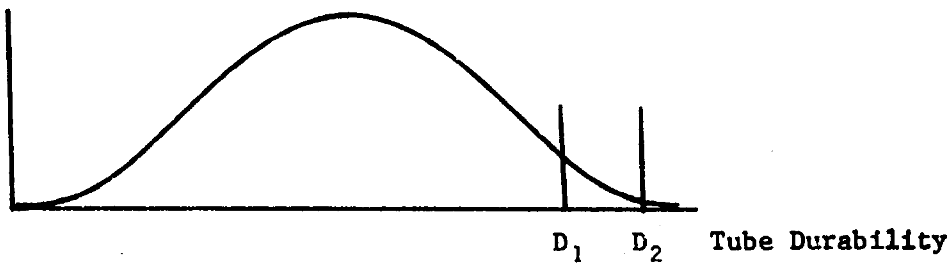
In each of the above outcomes, the life cycle cost was based on replacing the tube at D_2 rounds. Since there was almost no risk associated with building a tube that would last 1,000 or 3,000 rounds and the difference in total life cycle cost is above $300 million there is no reasons not to demand the 3,000 round tube. Similarly, a $59 million savings can be expected with only a 4% probability of rejection increase by requiring a 5,000 round tube. As the Durability requirement is increased to 7,500 and 10,000 the percentage of savings vs. the increased probability of rejection makes one question the advisability of demanding these higher requirements. Since the simulation considers a $1 savings just as important as a $1 billion dollar savings in its effort to optimize and in addition it was assumed (See Section "Additional Work Required") that the state-of-the-art was no barrier; the simulation forced the recommended durability values for the tube to the upper boundary set in the simulation.

Realizing that the state-of-the-art would be a barrier at these high levels one additional sensitivity run was made. The program test logic was changed to ignore any tube requirements and the life cycle cost was calculated based on replacing the tube at whatever wearout life could be designed for each iteration. (This would be similar to using pull-over guages.) This resulted in a total life cycle cost of 6.2239×10^9 which was even less than the case when $D_2 = 10{,}000$ rounds. In an effort to explain this outcome consider the following three cases.

1)



2)



3) No decision made on tube

The curve represents the prior probability density of the expected tube durability parameter. D_1 and D_2 define the acceptance, [illegible] rejection region defined earlier (See Loss Function). Assume the probability density curve is the same for all three cases.

In Case 1 the rejection region is inconsequential in contribution to the expected loss. The acceptance region is large, but the longer durability life is not considered as tube replacements are based on the acceptance requirement D_2 (See Loss Function Case 0). In Case 2, the acceptance region is inconsequential. The rejection region is high in probability causing frequent rejection of the system with resulting expenditures in development of a system that meets the specified requirements, D_2, for all subsystems; and additional testing funds to validate these requirements.

Case 2 was preferred to Case 1 as the additional expenditures produce high durability while much of the predicted durability would not be utilized under Case 1.

Case 3 was preferred to Case 2: Again $D > D_2$ occurs with small probability. $D_1 < D < D_2$ results in expenditures which are approximately the same for Cases 2 and 3. If $D < D_1$ then Case 3 replaces tubes based on test estimates of durability avoiding the waste incurred by Case 1 and the expense of a new development program recommended in Case 2.

These recommendations are sensitive to the predicted estimates on tube durability. A pessimistic prediction of tube wear leads to a recommendation of Case 2 over Case 3.

The conclusions of this analysis are:

1) Expected loss is highly dependent on tube durability.

2) Sufficient tube testing should be performed to establish tube durability rather than base replacements on requirements.

3) Attainment of higher tube life is a basis of rejecting the program according to the logic of the simulation. A more realistic action would be initiation of a program to achieve a state-of-the-art tube.

4) A study should be initiated after test to evaluate the durability of the tube compared to the state-of-the-art. A study similar to this should be performed to determine benefits to be derived from accepting the tested tube design or, alternatively proceeding with a tube development program.

5) No decision regarding a tube durability requirement should be made at this time in view of the sensitivity of this parameter.

For the carriage, recoil and breech durability the "D_2" values as shown in the "RECOMMENDATIONS" section represent the recommended design goals or acceptance values for each subsystem. The sensitivity analysis conducted by varying the prior probability distribution for each subsystem show that if the designers risk profile were in error up to 25% in either direction, the difference in the total expected loss in still close to the variability of the simulation and therefore the results are not overly sensitive to these inputs within the ±25% bands. The analysis of the simulation indicates that the reduced maintenance/replacement cost that would result by raising the D_2 values does not offset the expected increase in loss due to the increased probability of system rejection and the associated redesign-retest and related cost.

The D_1 values represent the minimum acceptable durability values. Any subsystem design which falls below these values should be rejected.

Below these points the combination of redesign cost, retest cost, probability of rejection, and cost of continuing the present system are favorable as compared to the increased maintenance/replacement cost that would be incurred by fielding a weapon system with these low values.

For system reliability the R_2 value represents the design goal and the reliability value at which the system should be fielded. The R_1 value represents the lowest value for which it would be advantageous to enter into a reliability growth program and grow the system reliability to R_2. (This is based on a "Duane" growth model with a slope of .523.) An analysis of the simulation indicates that this growth slope is extremely optimistic and that a more realistic growth model needs to be developed before any recommendation can be made on the value for R_1. If the system reliability falls below R_1 then the system should be rejected and a complete redesign effort should be initiated. Until a more realistic growth model can be incorporated into the simulation, it is recommended that reliability level presently exhibited by the M102 105MM Howitzer system be used for R_1, i.e. 400 rnds.

ADDITIONAL WORK REQUIRED

As with any study concerned with cost-effectiveness analysis certain assumptions must be made when formulating the study. Since this study was the first attempt to optimize the design requirement in this manner there were several areas where simplifying assumptions were made which now deserve further study. The following is a list of these assumptions and the recommended work to be done in each area.

Assumption 1 - Throughout the Loss Function, whenever the system was rejected, it was assumed that the next design effort would produce a system which would meet all of the specified design requirements.

Work Required - The difference between the performance levels demonstrated and those required should be examined. Feasible growth rates should be examined and comparisons with the state-of-the-art should be made. Instead of assuming the next design will be acceptable, the subjective input distribution should be adjusted in accordance with feasible growth rates within the time allowed and the complete test cycle should be reiterated. For cases where an advancement in the state-of-the-art is required the cost associated with the design effort should be weighed accordingly.

Assumption 2 - If any one subsystem, any combination of subsystems or the entire system was rejected as a result of the test, it was assumed that a complete system redesign would be made.

Work Required - Determinations must be made as to which subsystems or the failure to meet which requirements will cause a complete redesign effort. If some combinations will not require a complete redesign then individual growth curves should be developed for those combinations so that a limited redesign or growth program can be programmed into the model. In addition it must be determined how the redesign system will be tested for acceptance or if it will be tested at all.

Assumption 3 - For the reliability loss function, case 6, it was assumed that the cost of a retrofit program would double the reliability growth cost.

Work Required - A better rationale for the cost of a retrofit program should be developed. Those weapons from the first years production may not be retrofit until they are overhauled, if at all.

Assumption 4 - During the exercise of the test phase, it was assumed that each weapon had its own individual maintenance support test package containing the major subsystem replacements.

Work Required - An alternative model should be developed in which the spare subsystems are contained in a common maintenance support test package and can be used on any weapon.

Assumption 5 - In obtaining the life cycle cost it was assumed that in the case of durability components, they would be replaced when failed except for the breech which was replaced after every 3rd tube.

Work Required - The durability replacement concept in the program needs to be changed to allow several maintenance options to be considered. The options for each subsystem are as follows:

Carriage - overhaul

1. overhaul only when durability failure occurs, T_f
2. overhaul after every T_p rounds or when failed if $T_f < T_p$
3. overhaul after every i^{th} tube or when failed if $T_f < (i \cdot \text{Tube Life})$

Recoils - overhaul

1. overhaul only when failure occurs and when carriage is overhauled
2. overhaul after every T_p rounds or when failed if $T_f < T_p$ and when carriage is overhauled
3. overhaul after every i^{th} tube or when failed if $T_f < (i \cdot \text{Tube Life})$ and when carriage is overhauled

Tube - replace with new one

1. replace only when worn out and when carriage is overhauled
2. replace after every T_p rounds and when worn out if $T_w < T_p$ and when carriage is overhauled

Note: When carriage is overhauled the tube will not be replaced if it has more than X% of its life left.

Breech - replace with new one

replace after every i^{th} tube or when failed if $T_f < (i \cdot \text{Tube Life})$ and when carriage is overhauled if the breech has less than X% of a tube life left

If a subsystem is overhauled or replaced before it fails then that regeneration point will not be counted as a durability failure. The expected number of renewal calculations should be modified to allow for the above options.

Assumption 6 - Whenever a reliability growth program is entered it is assumed that the required testing-redesign cycle can be accomplished before production begins.

Work Required - The time required to grow the system to an acceptable value should be examined. If the time is extensive the program will have to be delayed and the life of the present system extended.

Assumption 7 - The slope of the reliability growth program was assumed deterministic.

Work Required - A probabilistic growth rate should be developed based on max, min and most likely values. The "Duane" type of model needs to be modified to realistically represent howitzer development efforts.

REFERENCES

1. Department of the Army Approved Materiel Need (MN) for 105mm Howitzer, Towed, CDOG Para 412b(30), May 1972.

2. Seminar on "Decision Analysis" Presented at the 11th Annual US Army Operations Research Symposium, 15-18 May 1972, Durham, North Carolina, Standford Research Institute, Menlo Park, California.

3. Mood, A. Introduction to the Theory of Statistics, McGraw-Hill Book Company, Inc., 1950.

APPENDIX A

This appendix contains the detailed operating costs along with the supporting rationale for the XM204, M102 & M101 Howitzer systems. In addition Table A-4 shows a composite M102/M101 operating cost based on the quantities of each that would be required to operate at the densities the XM204 will operate at. The data in this appendix was computed and furnished as input to the study by the Comptroller (AMSWE-CPE).

TABLE A-1

XM204

Annual Unit Operating Costs

(FY 73 Dollars)

Crew		$67,723
Pay and Allowances	$54,169	
Replacement Training	7,366	
Separation Pay and Travel	921	
PCS Travel	2,195	
Medical Activities	2,124	
Other General Personnel Activities	210	
Administrative and Associated Activities	738	
Maintenance		1,178
Pay and Allowances	$746	
Replacement Training	312	
Separation Pay and Travel	18	
PCS Travel	43	
Medical Activities	41	
Other General Personnel Activities	4	
Administrative and Associated Activities	14	
Repair Parts		193
Ammunition		7,640
Integrated Logistics Support		6,243
Overhaul		2,151
Annual Unit Operating Cost		$85,128

XM204 Supporting Rationale

I. Crew

A. Pay and Allowances -

Crew pay and allowances were estimated for a nine-man crew. The military pay and allowances (MPA) cost factors in AWCP 37-2, Financial Administration, Cost Data, were modified as follows to arrive at the costs shown in the table below. The base pay portion of the MPA cost factor was increased by 6.42% for the 1 Jan 73 anticipated pay raise. Costs for the crew were estimated as follows:

Crew Member	MOS	Grade	Qty	Base Pay	Allowances	Yearly Cost
Section Chief	13B40	E-6	1	$ 7,222	$1,908	$ 9,130
Gunner	13B40	E-5	1	5,323	1,439	6,762
Assistant Gunner	13B40	E-4	1	4,575	1,216	5,791
Prime Mover Driver	13A10	E-4	1	4,575	1,216	5,791
Cannoneer	13A10	E-3	5	21,520	5,175	26,695
TOTAL			9			$54,169

B. Replacement Training -

Crew replacement training costs were estimated using the 27% enlisted personnel attrition factor in the Army Force Planning Cost Handbook (AFPCH) and course costs furnished by CONARC. Course costs are as follows:

MOS	Rank	OMA Cost	MPA Cost	Total
13A10/13B40	E-3/E-4	$226	$1,470	$1,696
13B40	E-5/E-6	$1,603	$6,101	$7,704

Replacement training costs of $7,366 per howitzer were computed by using the following equation: .27[7($1,696) + 2($7,704)] = $7,366.

C. Separation Pay and Travel -

This cost category is for separation travel and pay for unit personnel attrition from the active Army. Annual unit separation costs were computed by multiplying the crew size (9) by the enlisted separation pay (\$279) and separation travel (\$100) and applying the enlisted personnel attrition factor (27%). This was computed to be \$921 per howitzer - 9 (\$279 + \$100)(.27) = \$921. Separation pay and travel and the attrition factor were taken from the AFPCH.

D. PCS Travel -

Permanent Change of Station (PCS) travel was computed using geographical end-item deployment and initial PCS deployment costs, PCS travel costs and annual rotation rates from the AFPCH. The average per howitzer PCS travel costs were estimated to be \$2,195.

E. Medical Activities -

Costs for this category were computed using geographical end-item deployment and medical activity cost factors by geographical area in the AFPCH. The average per medical activities costs per howitzer were estimated to be \$2,124.

F. Other General Personnel Activities -

Costs for this category were also computed using the planned XM204 geographical end-item deployment and other general personnel activities factors in the AFPCH. The average per howitzer costs for this category were estimated to be \$210.

G. Administrative and Associated Activities -

These costs were computed using the proposed XM204 geographical deployment and applicable factors in the AFPCH. The average per howitzer costs for this category were computed to be \$738.

II. Maintenance

A. Pay and Allowances -

WECOM maintenance engineering personnel estimated that 288 man-hours per howitzer per year would be required for organizational (org), direct support (DS), and general support (GS) maintenance. This estimate was based on experience with the M101A1 and M102 Howitzers. The 288 man-hours represent .126 man-years. The hourly rate at each level of maintenance was calculated as the arithmetic average of the grades at that maintenance level, as shown below:

	Org	DS	GS
E-3	$2.33		
E-4	2.53	$2.53	
E-5		2.95	$2.95
E-6			3.99
TOTAL	$4.86	$5.48	$6.94
AVERAGE	$2.43	$2.74	$3.97

These hourly rates were computed from the modified annual MPA rates (see I.A.) in AWCP 37-2 and 2,288 annual working hours.

Applying the above average rates to the "hands-on" maintenance man-hours results in the following annual maintenance labor cost per howitzer:

ORG		DS		GS		TOTAL	
M/Hrs	Cost	M/Hrs	Cost	M/Hrs	Cost	M/Hrs	Cost
205.0	$498	66.0	$181	17.0	$67	288.0	$746

B. Replacement Training -

Maintenance personnel replacement training costs were estimated using the 27% enlisted personnel attrition factor in the AFPCH, course costs furnished by CONARC, and an indirect factor of 39% for non-productive

time from the Research Analysis Corporation report, Selected Uniform Cost Factors: A Manual for the Army Materiel Command, RAC-TP-451, June 1972. Approximately 99% of the maintenance labor is either performed by MOS 45L or 41C with 80% as 45L. Replacement training costs for each MOS can be calculated by the following equation:

$$\frac{\text{Maint M/Hrs + INDIRECT}}{\text{Annual Man-Hours}} \times \text{Course Cost} \times \text{Attrition Factor} = \text{Repl Tng Cost}$$

The annual man-hours were estimated at 2,288.

MOS	M/Yrs	x Course Cost	x Attrition Factor	= Per Howitzer Course Cost
41C	.035	$8,789	.27	$ 83
45L	.140	$6,063	.27	$229
			Cost Per Howitzer:	$312

C. Separation Pay and Travel -

This cost category is for separation travel and pay for unit personnel attrition from the active Army. Annual unit separation costs were computed by multiplying the maintenance personnel man-years (.175) by the enlisted personnel separation pay ($279) and separation travel ($100) and applying the enlisted personnel attrition factor (27%). This was calculated to be $18 per howitzer - .175 ($279 + $100)(.27) = 18. Separation pay and travel and the attrition factor were taken from the AFPCH.

D. PCS Travel -

PCS travel was computed using geographical end-item deployment and initial PCS deployment costs, PCS travel costs and annual rotation rates from the AFPCH. The average per howitzer PCS travel costs were estimated to be $43.

E. Medical Activities -

Costs for this category were computed using the planned XM204 geographical deployment and medical activity cost factors in the AFPCH. The average per medical activities costs per howitzer were estimated to be $41.

F. Other General Personnel Activities -

Costs for this category were also computed using the planned XM204 geographical deployment and other general personnel activities factors in the AFPCH. The average cost per howitzer for this category is $4.

G. Administrative and Associated Activities -

These costs were computed using the proposed XM204 geographical deployment and applicable factors in the AFPCH. The average per howitzer costs for this category were computed to be $14.

III. Repair Parts

Based upon M102 historical data, it was found that the cost of repair parts equated to $.84 per round in training when quantities of less than 500 rounds per howitzer per year were fired. Common Table of Allowances (CTA) 23-100-6, Ammunition, Rockets, and Missiles for Unit Training - Active Army and Reserve Components, shows 230 rounds per howitzer per year. With this data, a repair parts cost of $193 per howitzer was estimated.

IV. Ammunition

From CTA 23-100-6 the annual service practice ammunition requirements were derived. The cost per standard round was obtained from Supply Bulletin 700-20, Army Adopted and Other Items of Materiel Selected for Authorization. It was further assumed that 10% of the training rounds would require the super propelling charge. This cost was provided by MUCOM.

	Qty	Unit Cost	Total Cost
M1 - HE	206	$30.74	$6,332
M67 TP-T	4	35.14	140
M84 Smoke	4	57.45	230
M84 HCBE	2	56.56	113
M60 WP	6	44.33	266
M314A1 Illum	8	46.84	375
XM200 Propelling Charge	23	8.01	184
			$7,640

V. Integrated Logistics Support

Costs in this category were estimated using factors in the AFPCH and proposed XM204 deployment. The factors used cover Central Supply Activities and Base Operations. A cost of $3,311 was estimated for Base Operation and $2,932 for Central Supply Activities, for a total of $6,243.

VI. Overhaul

Overhaul costs were estimated based upon a cost estimating relationship (CER) for self-propelled howitzers, 40 mm anti-aircraft guns, and towed howitzers with a standard price over $40,000. This CER is published in AWCP 37-2. Based upon an estimated standard price of $62,869, an overhaul cost of $10,755 was estimated which was prorated over the mean time between overhaul of five years, for an annual cost of $2,151.

TABLE A-2

M102

Annual Unit Operating Costs

(FY 73 Dollars)

Crew		$67,562
Pay and Allowances	$54,169	
Replacement Training	7,366	
Separation Pay and Travel	921	
PCS Travel	2,103	
Medical Activities	2,062	
Other General Personnel Activities	213	
Administrative and Associated Activities	728	
Maintenance		1,618
Pay and Allowances	$1,047	
Replacement Training	411	
Separation Pay and Travel	24	
PCS Travel	56	
Medical Activities	55	
Other General Personnel Activities	6	
Administrative and Associated Activities	19	
Repair Parts		193
Ammunition		7,456
Integrated Logistics Support		6,447
Overhaul		1,753
Annual Unit Operating Cost		$85,029

M102 Supporting Rationale

I. Crew

A. Pay and Allowances -

Crew pay and allowances for the M102 were estimated to be the same as for the XM204 because each has a nine man crew.

B. Replacement Training -

These costs were also estimated to be the same as those estimated for the XM204 because the crews for the two howitzers are identical.

C. Separation Pay and Travel -

Crew separation pay and travel costs per howitzer for the M102 were assumed to be the same as for the XM204 because the crew size for both howitzers is the same.

D. PCS Travel -

These costs were computed based upon the same methodology used to estimate costs for this category on the XM204. The M102 deployment data were furnished by AMSWE-MMF. Costs of $2,103 per howitzer were estimated.

E. Medical Activities -

These costs were also computed based upon the same methodology used to estimate costs for this category on the XM204. Costs of $2,062 per howitzer were estimated.

F. Other General Personnel Activities -

These costs were also computed based upon the same methodology used to estimate costs for this category on the XM204. Costs of $213 per howitzer were estimated.

G. Administrative and Associated Activities -

These costs were also computed based upon the same methodology used to estimate costs for this category on the XM204. Costs of $728 per howitzer were estimated.

II. Maintenance

A. Pay and Allowances -

Maintenance man-hours were taken from the Coordination Draft of the US Army Combat Developments Command Manpower Authorization Criteria for Armament Maintenance, dated January 1972, and AR 570-2, Organization and Equipment Authorization Tables - Personnel. A total of 393 "hands-on" maintenance man-hours were estimated. The hourly rate at each level of maintenance was calculated as the arithmetic average of the grades at that maintenance level, as shown below:

	Org	DS	GS
E-3	$2.33		
E-4	2.53	$2.53	
E-5		2.95	$2.95
E-6			3.99
TOTAL	$4.86	$5.48	$6.94
AVERAGE	$2.43	$2.74	$3.97

These hourly rates were computed from the annual MPA rates in AWCP 37-2, as adjusted to FY 73 dollars, and 2,268 annual working hours.

Applying the above average rates to the 393 "hands-on" maintenance man-hours results in the following annual maintenance labor cost per howitzer:

Org		DS		GS		TOTAL	
M/Hrs	Cost	M/Hrs	Cost	M/Hrs	Cost	M/Hrs	Cost
247	$600	108	$296	38	$151	393	$1,047

B. Replacement Training -

The following data for maintenance personnel replacement training on the XM204 were estimated to be the same for the M102.

1. Course cost for MOS 45L - $6,063 per student.
2. Course cost for MOS 41C - $8,789 per student.
3. Enlisted personnel attrition factor - 27%.
4. Non-productive time factor - 39%.

Using the same methodology as used to calculate replacement training costs for the XM204 maintenance personnel, the following costs were estimated for a M102 howitzer:

MOS	M/Yrs	x Course Cost	x Attrition Factor	= Per Howitzer Course Cost
41C	.028	$8,789	.27	$ 66
45L	.211	$6,063	.27	$345
			Cost Per Howitzer:	$411

C. Separation Pay and Travel -

Costs for this category were estimated using the same methodology as used to estimate these costs for the XM204. Costs of $24 per howitzer were estimated for the M102.

D. PCS Travel -

These costs were computed based upon the same methodology used to estimate costs for this category on the XM204. Costs of $56 were estimated for this category.

E. Medical Activities -

Medical activities costs were also computed based upon the same methodology used to estimate costs for this category on the XM204. Costs of $55 per howitzer were estimated.

F. Other General Personnel Activities -

These costs were computed based upon the same methodology used to estimate costs for this category on the XM204. Costs of $6 per howitzer were estimated.

G. Administrative and Associated Activities -

Costs for this category were also computed based on the methodology used to estimate costs for this category on the XM204. Costs of $19 per howitzer were estimated.

III. Repair Parts

Based upon M102 historical consumption data, it was found that the cost of repair parts equated to $.84 per round in training when quantities of less than 500 rounds per howitzer per year were fired. CTA 23-100-6 shows 230 rounds per howitzer per year. Based on this number of rounds, a per howitzer repair parts cost of $193 was estimated.

IV. Ammunition

With exception of the super propelling charge, ammunition requirements for the M102 are the same as for the XM204. Therefore, costs estimated for the XM204, less the XM200 propelling charge costs, are applicable to the M102.

V. Integrated Logistics Support

Integrated logistics support costs were estimated using the same methodology used on the XM204. Costs of $3,523 were estimate for Base Operation and $2,924 for General Supply Activities for a total of $6,447.

VI. Overhaul

Overhaul costs for the M102 were estimated at $8,765. This is the FY 72 overhaul cost adjusted to FY 73 dollars by 1.028. Based upon a mean time between overhaul of five years, an annual cost of $1,753 was estimated.

TABLE A-3

M101A1

Annual Unit Operating Costs

(FY 73 Dollars)

Crew		$65,914
Pay and Allowances	$54,169	
Replacement Training	7,366	
Separation Pay and Travel	921	
PCS Travel	562	
Medical Activities	1,889	
Other General Personnel Activities	195	
Administrative and Associated Activities	812	
Maintenance		1,550
Pay and Allowances	$1,031	
Replacement Training	[illegible]	
Separation Pay and Travel	[illegible]	
PCS Travel	15	
Medical Activities	50	
Other General Personnel Activities	5	
Administrative and Associated Activities	21	
Repair Parts		164
Ammunition		7,456
Integrated Logistics Support		4,557
Overhaul		1,083
Annual Unit Operating Cost		$80,724

M101A1 Supporting Rationale

I. Crew

A. Pay and Allowances -

Crew pay and allowances for the M101 were estimated to be the same as for the XM204 because both howitzers have the same crew composition.

B. Replacement Training -

These costs were also estimated to be the same as those estimated for the XM204 because the crews for the two howitzers are identical.

C. Separation Pay and Travel -

Crew separation pay and travel costs per howitzer for the M101A1 were assumed to be the same as for the XM204 because the crew size for both howitzers is the same.

D. PCS Travel -

These costs were computed based upon the same methodology used to estimate costs for this category on the XM204. The M101A1 deployment data were furnished by AMSWE-MMF. Costs of $562 per howitzer were estimated.

E. Medical Activities -

These costs were also computed based upon the same methodology used to estimate costs for this category on the XM204 [illegible] f $1,889 per howitzer were estimated

F. Other General Personnel Activities -

Other general personnel activities costs were also computed based upon the same methodology used to estimate costs for this category on the XM204. Costs of $195 per howitzer were estimated.

G. Administrative and Associated Activities -

These costs were also computed based upon the same methodology used to estimate costs for this category on the XM204. Costs of $812 per howitzer were estimated.

II. Maintenance

A. Pay and Allowances -

Annual maintenance man-hours were derived from the same sources used for the M102 maintenance man-hours. A total of 388 "hands-on" maintenance man-hours were estimated. The average hourly rates used are the same as was used on the M102 and XM204. By applying the average hourly rates to the 388 "hands-on" maintenance man-hours results in the following annual maintenance labor cost per howitzer:

Org		DS		GS		TOTAL	
M/Hrs	Cost	M/Hrs	Cost	M/Hrs	Cost	M/Hrs	Cost
247	$600	105	$288	36	$143	388	$1,031

B. Replacement Training -

The following data for maintenance personnel replacement training on the XM204 were estimated to be the same for the M101A1:

1. Course cost for MOS 45L - $6,063 per student.
2. Course cost for MOS 41C - $8,789 per student.
3. Enlisted personnel attrition factor - 27%.
4. Non-productive time factor - 39%.

Using the same methodology as used to calculate replacement training costs for the XM204 maintenance personnel, the following costs were estimated for a M101A1 Howitzer:

MOS	M/Yrs x	Course Cost x	Attrition Factor =	Per Howitzer Course Cost
41C	.025	$8,789	.27	$ 59
45L	.211	$6,063	.27	$345
			Cost Per Howitzer:	$404

C. Separation Pay and Travel -

Separation pay and travel costs were estimated using the same methodology used to estimate these costs for the XM204. Costs of $24 per howitzer were estimated for the M101A1.

D. PCS Travel -

These costs were also computed based upon the same methodology used to estimate these costs for the XM204. Costs of $15 were estimated for this category.

E. Medical Activities -

Medical activities costs were also computed based upon the same methodology used to estimate these costs on the XM204. Costs of $50 per howitzer were estimated for the M101A1.

F. Other General Personnel Activities -

These costs were computed based upon the same methodology used to estimate costs in this category for the XM204. Costs of $5 per howitzer were estimated.

G. Administrative and Associated Activities -

Costs for this category were also estimated based on the methodology used to estimate these costs for the XM204. Costs of $21 per M101A1 Howitzer were estimated.

III. Repair Parts

There are no valid peacetime consumption data on the M101A1 Howitzer. A comparison of estimated wartime costs shows the M101A1 parts consumption costs to be approximately 52% of the M102. Based upon discussions with maintenance engineering personnel, it was decided that in peacetime the difference between the two howitzers would not be that great. It was estimated that the M101A1 would consume somewhere between 80 90 percent of the consumption on the M102. The mid-point of the range, 85%, was used to estimate a repair parts consumption cost of $164 per howitzer.

IV. Ammunition

Ammunition consumption in training is the same for the M101A1 as for the M102. Therefore, ammunition costs of $7,456 were estimated for the M101A1.

V. Integrated Logistics Support

Integrated logistics support costs were estimated using the same methodology used on the XM204. Costs of $2,627 were estimated for Base Operation and $1,930 for Central Supply Activities for a total per howitzer cost of $4,557.

VI. Overhaul

Overhaul costs for the M101A1 were estimated at $5,413. This is the FY 72 overhaul cost inflated to FY 73 dollars by a factor of 1.028. Based upon a mean time between overhaul of five years, an annual cost of $1,083 was estimated.

TABLE A-4

M101A1/M102
ANNUAL UNIT OPERATING COSTS
(FY 73 Dollars)

Crew		$67,723
Pay and Allowances	$54,169	
Replacement Training	7,366	
Separation Pay and Travel	921	
PCS Travel	2,195	
Medical Activities	2,124	
Other General Personnel Activities	210	
Administrative and Associated Activities	738	
Maintenance		1,605
Pay and Allowances	1,044	
Replacement Training	410	
Separation Pay and Travel	24	
PCS Travel	45	
Medical Activities	56	
Other General Personnel Activities	6	
Administrative and Associated Activities	20	
Repair Parts		188
Ammunition		7,458
Integrated Logistics Support		6,287
Overhaul		1,644
Annual Unit Operating Cost		$83,903 1/

1/ Represents the average unit annual operating costs for a specific quantity (classified confidential) of M102 and M101A1 Howitzers.